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SOURCE Doklady Akademii Nauk SSSR, Vol LXXI, No 5, 1950.NUCLEAR SPIN'S INFLUENCE ON RESONANCE PARAMAGNETIC ABSORPTION  
IN Mn AND Cu SALT SOLUTIONSS. A. Al'tshuler  
B. M. Kozyrev  
S. G. Salikhov

Magneto-spin resonance has been discovered by relaxation losses in a weak variable magnetic field  $H_1$  perpendicular to constant  $H_0$ . (The absorption maximum of  $Q = Q(H_0)$  is determined from:  $\nu = \frac{g\mu_B}{h} H_0$ .)

Up to now, solid salts of  $Mn^{++}$ ,  $Cu^{++}$ ,  $Cr^{+++}$  have indicated that the maximum corresponds to  $g \approx 2$ . This agrees with their static susceptibility and is explained by the strong action of the electric field of neighboring atoms which disrupts the bond of the orbital moment with the spin in a paramagnetic field so that only the spin can rotate freely in space. However, B. M. Kozyrev's measurements on erbium and cerium salt solutions produced absorption maxima corresponding to g-factor  $\sim 1.14$  for trivalent erbium and  $\sim 0.9$  for trivalent cerium, in agreement with theory.

Mn and both Cu isotopes have nuclear mechanical and magnetic moments. The question naturally arose as to the possible influence of nuclear spin on the absorption curve, noticeable only if the bond of nuclear and electron spins was not completely disrupted by the external magnetic field  $H_0$  and internal field created by the spins of neighboring ions.

The binding energy of nuclear and electron spins can be roughly evaluated optically from hyperfine structure. In paramagnetic  $Mn^{++}$  and  $Cu^{++}$  salts, the spin of the electron shell is created by d-electrons, and therefore the binding energy can be considered about  $0.01 \text{ cm}^{-1}$ , indicating that a 1,000-oersted field can separate the electron spin from the nucleus and hide the sought-for effect.

The average internal field in paramagnetic salt crystals may reach 1,000 oersteds. They can, however, be decreased by a paramagnetic solution in diamagnetic liquid.

Low-frequency fields ( $10^8$  cycles) are necessary to use small external fields  $H_0$ .

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Thus, one can expect absorption curves with several maxima instead of one maximum corresponding to transitions between neighboring equidistant energy levels of electron spin in a magnetic field. These maxima should correspond to transitions between levels, whose positions can be determined by the Zeeman effect in intermediate fields.

For lower concentrations, the Zeeman effect in weak fields will hold and the absorption curve will have maxima corresponding to the g-factor of the resulting spin of the nucleus and shell:

$$g_F = g_e \frac{F(F+1) + J(J+1) - I(I+1)}{2F(F+1)}$$

where  $g_e$  is Lande splitting factor for electron shell;  $F$ , resulting spin of nucleus and shell;  $J$ , electron spin; and  $I$ , nuclear spin.

Resonance paramagnetic absorption in solutions of  $Mn^{++}$  salts was discovered by Ye. K. Zavoytskiy (ZhETF, 15, 344, 1945); since his measurements were made at low frequencies ( $10^6$ - $10^7$  cycles), the position of the absorption maximum could not be established accurately.

We undertook the study of resonance absorption in  $MnCl_2$  solutions at  $2.07 \cdot 10^8$  cycles by reaction on a generator (S. A. Al'tshuler, Ye. K. Zavoytskiy, and B. M. Kozyrev, ZhETF, 14, 407, 1944). It turned out that for concentrations of  $MnCl_2$  above one mole per liter the absorption curve has a blurred maximum corresponding to  $g_e/2$ , possibly because the nuclear spin begins to act even at this high concentration. With 0.5 mole per liter, there is one sharply defined maximum corresponding to  $g \approx 1$  (see I and II in the appended figure).

According to the optical data of White and Ritschl (Phys Rev 35, 11, 146 1930), the mechanical moment of the manganese nucleus is  $I = 5/2$ . The electron spin of  $Mn^{++}$  is also equal to  $5/2$ . By virtue of this,  $g_F$  must equal  $g_e/2$ , i.e., 1 for all values of the resulting spin  $F$  of the nucleus and shell of  $Mn$ .

Thus, for  $Mn$ , our experiment agrees with the Zeeman effect in weak fields.

We also investigated absorption in  $Cu(NO_3)_2$ . The  $Cu^{++}$  ion has a resulting electron spin of  $J = \frac{1}{2}$ , while the atomic nucleus of  $Cu$ , as is well known (R. Ritschl, Az. f. Phys., 79, 1, 1932), has  $I = 3/2$ .

This case corresponds to the Zeeman effect in intermediate fields. The small values of  $J$  and  $I$  should lead to a simple system of levels and consequently to few absorption maxima. Actually, for  $0.686 \cdot 10^8$  cycles and 1.6 moles per liter, the curve gave several blurred maxima (see III in the appended figure). The transition from intermediate fields to weak by dilution could not be made, apparently because the bond between nuclear and electron spins of  $Cu^{++}$  is considerably weaker than in  $Mn$ , due mainly to the electron spin of the  $Mn^{++}$  being 5 times greater than in  $Cu^{++}$ . Therefore, we propose to investigate absorption in weak solutions of bivalent copper salts at lower frequencies.

In conclusion, we note that our determination of nuclear spin exceeds Bloch's nuclear induction (Phys Rev 70, 460, 1936) in that our effect is hundreds of times greater. Unfortunately, it can be used only for paramagnetic ions.

[Appended figure follows]

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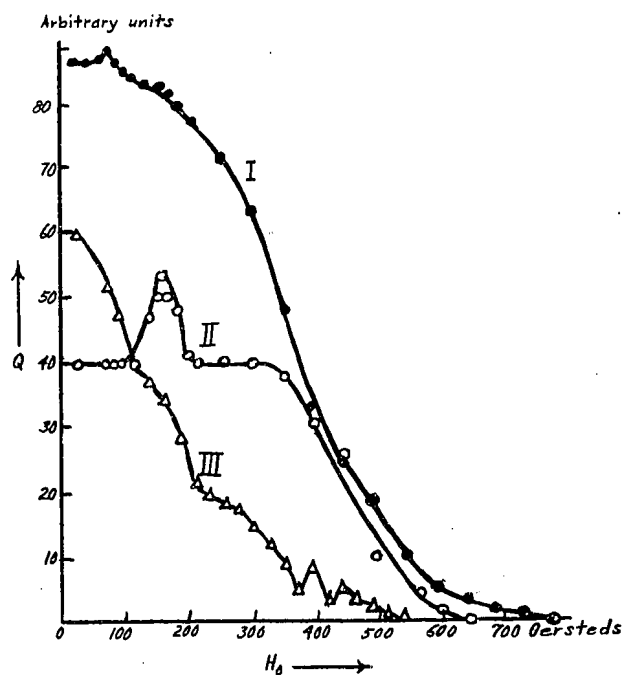
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$T = 292^{\circ} \text{K}$

I:  $\lambda = 145 \text{ cm}$ ,  $\text{MnCl}_2$  in water, 3 mol/liter

II:  $\text{MnCl}_2$  in water 0.5 mol/liter

III:  $\text{Cu}(\text{NO}_3)_2$  in water 1.6 mol/liter

IV:  $\text{Cu}(\text{NO}_3)_2$  in water 1.6 mol/liter

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